Postdoctoral position at ENSTA Bretagne: Signal Processing and Ocean Acoustics

Mode filtering in shallow water using time-frequency analysis and non-linear sampling

1 Context

Many physical or technical situations involve the propagation of a wave through a dispersive medium (ultrasonic waves in bones, electromagnetic whistlers in the magnetosphere...). When considering broadband propagation, each frequency component travels with its own speed, and a propagating nonstationary signal is distorted during its propagation. Dispersion usually tends to complicate the received signal, particularly in complex environments where propagation is dominated by multiple modal components, and this often limits the ability to directly recover information from the signal. On the other hand, the dispersion effects convey information about the propagation medium and the source/receiver configuration. If properly characterized using suitable signal processing methods, dispersion can then be used as the basis of inversion algorithms. In particular, when considering a transient source signal in a single receiver configuration, the received signal is nonstationary, and **time-frequency analysis** is the most common tool for dispersion analysis.

2 Project

The project focuses on underwater acoustics, and more particularly on low frequency (0-500 Hz) propagation in shallow waters (water depth $D < 200$ m). In this case, the oceanic environment acts as a **dispersive waveguide**, and propagation can be described by **normal-mode theory** [Jensen et al., 2011]. If properly characterized using suitable signal processing methods, dispersion can be exploited to invert environmental properties (e.g. source localization and/or sediment characteristics). Existing methods consists in 2-step algorithms: 1) separation of the modes (i.e. modal filtering) and 2) estimation of the environmental parameters using modal features (e.g. [Potty et al., 2000, Bonnel et al., 2013a]). In this context, the aim of the project is to develop new signal processing methods allowing modal filtering in shallow waters.

3 Research subject

Previous work has demonstrated that single receiver mode filtering is possible using time-frequency analysis and a method called **warping** [Bonnel et al., 2011]. Warping is actually a **non-linear sampling** on the signal. Such resampling is performed using a mathematical *warping function*, which usually derives from a simple model of the environment. Warping is known to be robust to environmental mismatch and thus allows modal filtering for real data. Nonetheless, modal filtering using warping presents some limitations, in particular regarding mode amplitude estimation.

The research subject will be divided into 2 main tasks: 1) understanding the problem associated to mode amplitude estimation using warping and 2) improving the mode amplitude estimation. Several phenomena will be studied to understand the mode amplitude estimation problem. Hypotheses that will be verified include 1) a possible contamination of low order modes by the high order modes, 2) a wrong design of the time-frequency filters used to separate the warped modes, 3) a mismatch between the (idealized) warping model and the true environment. Mode filtering capacities will be improved based on the results of the previous task. A foreseeable improvement will come from choosing wisely the warping function. Two options will be considered. On the first hand, it is possible to define the warping function using an adapted -but simple- environmental approximation. In this case, all the mode will be warped with a single transform but none of them will be perfectly warped (e.g. [Bonnel et al., 2013b]). On the other hand, it is possible to use all the available environmental information (e.g. [De Marchi et al., 2009]). In this case, one mode will be perfectly warped, but it will be necessary to change the warping function to warp another mode.

4 Qualifications

The project is based on a synergy between signal processing and acoustics. Applicants must have a Ph. D degree in either signal processing or acoustics. A research experience in underwater acoustics would be appreciated. Skills in time-frequency analysis and/or modal propagation in dispersive medium would be a plus. Applicant must be fluent in Matlab.

5 Practical information

- Duration: 12 months
- Funding: Office of Naval Research Global
- Net salary: $\simeq$ 1950 €/ month
- Localization: ENSTA Bretagne, Lab-STICC (UMR CNRS 6285), 2 rue Francois Verny, 29806 Brest cedex 9, France
- Start date: as soon as possible

6 Application procedure

All applicants must submit a cover letter, a CV, and a publication list. Any other material (e.g. a personal statement) that might strengthen the application is welcome. All materials must be sent electronically to Julien Bonnel (see contact below).

7 Contact

Julien Bonnel, +33 2 98 34 89 69, julien.bonnel@ensta-bretagne.fr

References

[Bonnel et al., 2013a] Bonnel, J., Dosso, S., and Chapman, R. (2013a). Bayesian geoacoustic inversion of single hydrophone light bulb data using warping dispersion analysis. *The Journal of the Acoustical Society of America*, 134:120–130.

[Bonnel et al., 2011] Bonnel, J., Gervaise, C., Roux, P., Nicolas, B., and Mars, J. (2011). Modal depth function estimation using time-frequency analysis. *The Journal of the Acoustical Society of America*, 130:61–71.

[Bonnel et al., 2013b] Bonnel, J., Le Touzé, G., Nicolas, B., and Mars, J. (2013b). Physics-based time-frequency representations for underwater acoustics: Power class utilization with waveguide-invariant approximation. *IEEE Signal Processing Magazine*, 30(6):120–129.

[De Marchi et al., 2009] De Marchi, L., Marzani, A., Caporale, S., and Speciale, N. (2009). Ultrasonic guided-waves characterization with warped frequency transforms. *Ultrasonics, Ferroelectrics, and Frequency Control, IEEE Transactions on*, 56(10):2232–2240.

[Jensen et al., 2011] Jensen, F., Kuperman, W., Porter, M., and Schmidt, H. (2011). *Computational Ocean Acoustics*. American Institute of Physics, New York, second edition.

[Potty et al., 2000] Potty, G., Miller, J., Lynch, J., and Smith, K. (2000). Tomographic inversion for sediment parameters in shallow water. *The Journal of the Acoustical Society of America*, 108:973–986.